

UNDERSEA TOPOGRAPHY AND
THE COMPARATIVE DISTRIBUTIONS OF
TWO PELAGIC CETACEANS

- MIDDAUGH, D. P., AND M. J. HEMMER.
1984. Spawning of the tidewater silverside, *Menidia peninsula* (Goode and Bean), in response to tidal and lighting schedules in the laboratory. *Estuaries* 7:139-148.
- MIDDAUGH, D. P., AND T. TAKITA.
1983. Tidal and diurnal spawning cues in the Atlantic silverside, *Menidia menidia*. *Environ. Biol. Fishes* 8:97-104.
- MILLER, C. A., J. M. WILSON, AND A. H. MEIER.
1981. Induction of semilunar rhythms of reproductive indices in *Fundulus grandis*. [Abstr.] *Am. Zool.* 21:995.
- NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION.
1981. Tide tables 1982, high and low water predictions, East Coast of North and South America including Greenland. U.S. Dep. Commer., 235 p.
- NEWMANN, D.
1978. Entrainment of a semilunar rhythm by simulated tidal cycles of mechanical disturbance. *J. Exp. Mar. Biol. Ecol.* 35:173-185.
- ROSS, R. M.
1983. Annual, semilunar, and diel reproductive rhythms in the Hawaiian labrid *Thalassoma duperrey*. *Mar. Biol. (Berl.)* 72:311-318.
- SAIGUSA, M.
1980. Entrainment of a semilunar rhythm by a simulated moonlight cycle in the terrestrial crab, *Sesarma haematocheir*. *Oecologia (Berl.)* 46:38-44.
- TAYLOR, M. H., AND L. DiMICHELE.
1980. Ovarian changes during the lunar spawning cycle of *Fundulus heteroclitus*. *Copeia* 1980:118-125.
1983. Spawning site utilization in a Delaware population of *Fundulus heteroclitus* (Pisces: Cyprinodontidae). *Copeia* 1983:719-725.
- TAYLOR, M. H., D. DiMICHELE, AND G. J. LEACH.
1977. Egg stranding in the life cycle of the mummichog, *Fundulus heteroclitus*. *Copeia* 1977:397-399.
- TAYLOR, M. H., L. DiMICHELE, M. M. LEVITAN, AND W. F. JACOB.
1979. Lunar spawning cycle in the mummichog, *Fundulus heteroclitus* (Pisces: Cyprinodontidae). *Copeia* 1979:291-297.
- THRALL, T., AND L. ENGELMAN.
1981. Univariate and bivariate spectral analysis. In W. J. Dixon (editor), *BMDP statistical software*, p. 604-638. Univ. Calif. Press, Los Ang.
- WAAS, B. P., AND K. STRAWN.
1983. Seasonal and lunar cycles in gonadosomatic indices and spawning readiness of *Fundulus grandis*. *Contrib. Mar. Sci., Texas A&M Univ.* 26:127-141.
- WEISBERG, S. B.
1981. Food availability and utilization by the mummichog, *Fundulus heteroclitus* (L.). Ph.D. Thesis, Univ. Delaware, Newark, 104 p.
- WELD, M. M., AND A. H. MEIER.
1982. Circadian gonadal responses to daily disturbances in gulf killifish. [Abstr.] *Am. Zool.* 22:866.

ANSON H. HINES
KENRIC E. OSGOOD
JOSEPH J. MIKLAS

Smithsonian Environmental Research Center
P.O. Box 28
Edgewater, MD 21037

Prey species are not uniformly distributed. Foraging efficiency, therefore, should be maximized when effort is concentrated in areas where prey are concentrated. Cetacean food is probably most concentrated in regions of high general productivity. Because the undersea topography may be a major influence on productivity, cetacean foraging patterns may be associated with the topographic patterns of the ocean floor (Hui 1979). I report here the occurrences of two species of pelagic odontocete cetaceans, the Pacific pilot whale, *Globicephala macrorhynchus*, and the common dolphin, *Delphinus delphis*, relative to seafloor topography and to diet. Although it is not clear if the genus *Delphinus* in this region is composed of two species or one species with two subspecies, the vast majority are *Delphinus delphis* (Banks and Brownell 1969; Evans 1975). If data from more than one species are included in this study, it is assumed that any interspecies difference in distribution relative to substrate was not significant to the analyses.

Methods and Results

This study was conducted in the Southern California Continental Borderland (Fig. 1) which consists of ridges, deep troughs, and basins (Chase 1968). There were 61 survey flights totaling 22,353 km. The flights were conducted at various times, all of them during midday (1000-1500) from 1968 through 1976. Totals of 1,057 pilot whales in 38 aggregations (in January, March, April, July, October, and December) and 47,105 common dolphins in 142 aggregations (in all months of the year) were observed. The survey methods have been previously described (Hui 1979).

The data for each species were not divided into temporal subsets as in Hui (1979), but were treated as whole sets. The distribution of each species was examined relative to depth and relative to change in depth. The method of analysis has been presented in detail elsewhere (Hui 1979).

Both pilot whales and common dolphins were distributed uniformly ($P > 0.10$) throughout the depth classes but not uniformly among the Contour Index (CI) classes ($P < 0.005$). For each species there were more observations than expected over the steepest bottom topography and fewer than expected over the flattest (Table 1).

I also compared the distribution of pilot whales

among CI classes to the distribution of common dolphins. Due to the small number of pilot whale aggregations, the CI range was divided into four

unequal classes to meet the statistical assumptions for chi-square analysis (Dixon and Massey 1969). The proportion of pilot whales in each of these classes

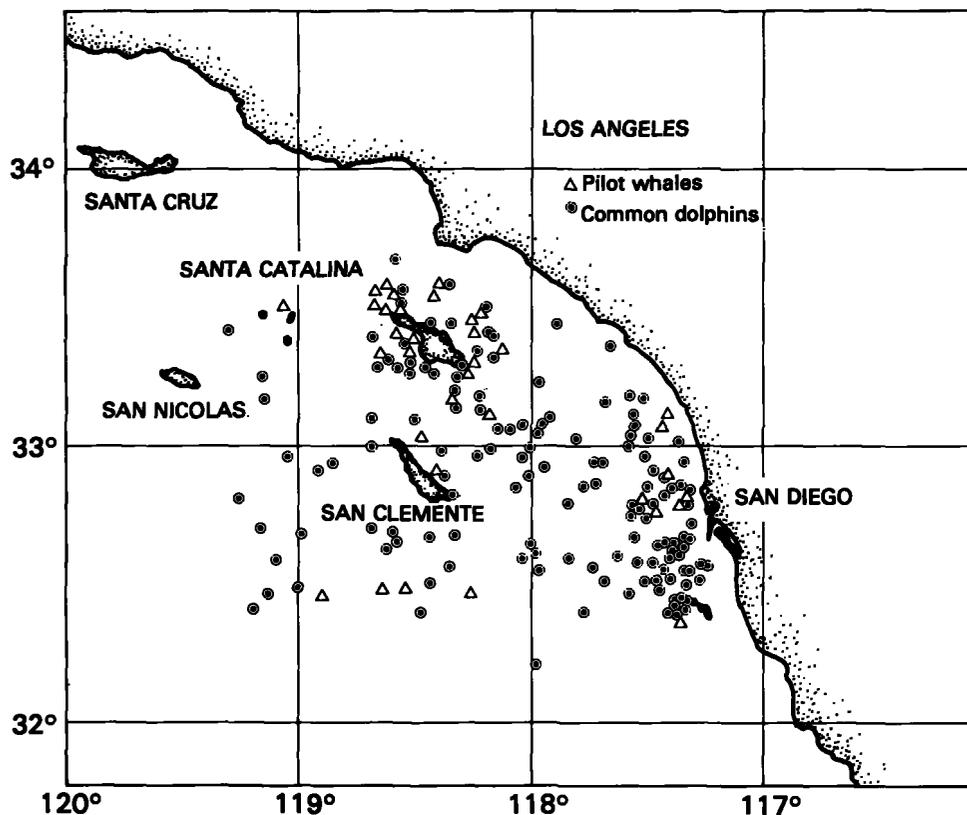


FIGURE 1.—Sightings of pilot whales, *Globicephala macrorhynchus*, and common dolphins, *Delphinus delphis*. The study area is bounded on the west by long. 120°00'W and on the east by the coast of California between lat. 34°05'N and 32°24'N. Sightings may not accurately depict the geographic distribution of these species because the survey flights were not uniformly distributed spatially or temporally. Encounters occurring outside the study area are not shown.

TABLE 1.—Distribution among contour index classes of observed and expected aggregations (see text).

Species	Contour index class	Number of aggregations		(F-f) ²
		Expected (F)	Observed (f)	F
Pilot whales	0.01-19.99	13.3	1	11.38
	20.00-39.99	6.3	5	0.27
	40.00-59.99	5.2	4	0.28
	60.00-79.99	7.4	10	0.91
	80.00-99.99	5.8	18	25.66
				$\chi^2 = 38.50$
Common dolphins	0.01-19.99	48.0	18	18.75
	20.00-39.99	23.2	27	0.62
	40.00-59.99	19.3	22	0.27
	60.00-79.99	27.2	21	1.41
	80.00-99.99	22.2	54	45.55
				$\chi^2 = 66.60$
				$\chi^2 (df = 4, P = 0.005) = 14.86$

was used to compute the expected number of common dolphins in that class.

The distribution of pilot whales was not the same as that of common dolphins among the CI classes ($P < 0.005$), particularly in the class for the lowest relief. Of the total chi-square value, 63% is due to proportionally more observations of dolphins than pilot whales in this one class (Table 2).

The distributions of the two sets of survey flights used to collect data for the two species were compared, but the CI range in this case was divided into 10 equal classes. The two sets of survey flights were equally distributed among the CI classes ($P > 0.10$).

TABLE 2.—Comparative distribution among contour index classes of pilot whales and common dolphins.

Contour index class	Dolphin aggregations		$(F-f)^2$ F
	Expected (F) ¹	Observed (f)	
0.01-39.99	22.4	45	22.80
40.00-59.99	14.9	22	3.38
60.00-79.99	37.4	21	7.19
80.00-99.99	67.3	54	2.63
			$\chi^2 = 36.00$
			$\chi^2 (df = 3, P = 0.005) = 12.84$

¹Computed from pilot whale sightings; see text.

Discussion

In the California Bight, pilot whales and common dolphins are distributed similarly above undersea topography of high relief, but common dolphins occur more frequently than pilot whales over areas of low relief. This difference may be linked to differences in feeding habits.

Pilot whales and common dolphins have significant morphological and physiological differences that are associated with their foods and feeding methods. Pilot whales are larger (7 m vs. 2 m in length) and have fewer but larger teeth (40 vs. 200) than common dolphins (Orr 1972). Pilot whales are capable of diving to 610 m (Bowers and Henderson 1972) while common dolphins dive to 257 m (Evans 1971).

The diet of the common dolphin in the Southern California Bight includes 19 species of fish, 2 species of squid, and miscellaneous crustaceans (Fitch and Brownell 1968; Evans 1975).

In contrast to common dolphins, pilot whales appear to be stenophagous, eating primarily squid. Atlantic pilot whales, *Globicephala melaena*, eat primarily squid (*Illex illecebrosus*). The only fish reported eaten (cod, *Gadus morhua*) composes <10% of the diet (Sergeant 1962). There has been no study on the Pacific pilot whale comparable with that of Sergeant's (1962) on the Atlantic form; however, the

stomachs of four wild Pacific pilot whales have been examined. They contained squid but no fish (W. A. Walker,¹ C. W. Woodhouse,² D. J. Seagars³). In captivity an Atlantic pilot whale rejected mullet (*Mugilidae*) and blue runner (*Carangidae*) fish and accepted only squid (probably *Loligo pealei*) until it was tricked into eating some herring (*Clupeidae*); and then the indications were that "He did not seem to digest the fish as well" (Kritzler 1949).

Squid distribution cannot be related to any particular bottom topography along the California coast because squids are not easily collected with sampling methods used in distribution studies (Mais 1974). However, it may be inferred that the narrow range of seafloor topographies visited by pilot whales reflects the narrow range of their diet and the areas where squid can be most easily caught by pilot whales.

Also concentrated over areas of canyons and escarpments are anchovies (Mais 1974), a major component of the dolphin diet (Fitch and Brownell 1968; Evans 1975). Common dolphins frequent these areas most. However, common dolphins are euryphagous. Some prey probably occur over seafloor of low relief, although this could not be confirmed from fish reports because bottom topography is not a parameter which is recorded in fish distribution studies. If some prey do occur over areas of low relief, their distribution would partially explain why dolphins occur over seafloor of low relief more frequently than do pilot whales.

My analyses show that the daytime distribution patterns of these two pelagic cetacean species are not random but are related to bottom topography. Although the distributions are similar, they are not the same. Differences in distributions may be due to the different foraging patterns but no firm conclusion can be drawn until more information is available.

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¹W. A. Walker, Research Associate, Section of Mammalogy, Natural History Museum of Los Angeles County, Los Angeles, CA 90007, pers. commun. July 1980.

²C. W. Woodhouse, Curator of Vertebrate Department, Santa Barbara Museum of Natural History, 2559 Puesta del Sol Road, Santa Barbara, CA 93105, pers. commun. July 1980.

³D. J. Seagars, Wildlife Biologist, National Marine Fisheries Service, Southwest Region, 300 S. Ferry St., Terminal Island, CA 90781, pers. commun. January 1981.

stomach contents of Pacific pilot whales. My special thanks to W. E. Evans of Hubbs Sea World Research Institute for his support and encouragement throughout this study, which was supported by ONR contract T0044 subproject RR0310201 (W. E. Evans, principal investigator), and NMFS agreement 01-6-200 11439.

Literature Cited

- BANKS, R. C., AND R. L. BROWNELL.
1969. Taxonomy of the common dolphins of the eastern Pacific ocean. *J. Mammal.* 50:262-271.
- BOWERS, C. A., AND R. S. HENDERSON.
1972. Project Deep Ops: Deep object recovery with pilot and killer whales. NUC TP 306, 86 p. Naval Undersea Center, San Diego, CA 92152.
- CHASE, T. E.
1968. Sea floor topography of central eastern Pacific Ocean. *Bur. Commer. Fish. Circular* 291, 33 p.
- DIXON, W. J., AND F. J. MASSEY, JR.
1969. *Introduction to statistical analysis*. 3d ed. McGraw-Hill, N.Y., 638 p.
- EVANS, W. E.
1971. Orientation behavior of delphinids: radio telemetric studies. *Ann. N.Y. Acad. Sci.* 188:142-160.
1975. Distribution, differentiation of populations, and other aspects of the natural history of *Delphinus delphis* Linnaeus in the northeastern Pacific. Ph.D. Thesis, Univ. California, Los Angeles, 164 p.
- FITCHE, J. E., AND R. L. BROWNELL, JR.
1968. Fish otoliths in cetacean stomachs and their importance in interpreting feeding habits. *J. Fish. Res. Board Can.* 25: 2561-2574.
- HUI, C. A.
1979. Undersea topography and distribution of dolphins of the genus *Delphinus* in the southern California bight. *J. Mammal.* 60:521-527.
- KRITZLER, H.
1949. The pilot whale at Marineland. *Natural History* 58: 302-308, 331-332.
- MAIS, K. F.
1974. Pelagic fish surveys in the California current. *Calif. Dep. Fish Game, Fish Bull.* 162, 79 p.
- ORR, R. T.
1972. *Marine mammals of California*. Univ. Calif. Press, Berkeley, 64 p.
- SERGEANT, D. E.
1962. The biology of the pilot or pothead whale *Globicephala melaena* (Traill) in Newfoundland waters. *Fish. Res. Board Can., Bull.* 132, 84 p.

CLIFFORD A. HUI

*Chemistry and Biochemistry Branch, Code 521
Naval Ocean Systems Center
San Diego, CA 92152-5000*

LARVAL AND JUVENILE GROWTH OF SABLEFISH, *ANOPLOPOMA FIMBRIA*, AS DETERMINED FROM OTOLITH INCREMENTS

The black cod or sablefish, *Anoplopoma fimbria*, has been the subject of an intensifying fishery off the west coast of North America over the last decade. Biological information on this species, however, including data on spawning, early life history, age and growth, and population structure, is relatively meager. Sablefish are widely distributed in the northern Pacific, with adults most abundant at depths of 366-915 m (Hart 1973). Mason et al. (1983) suggested that eggs are spawned and developed in waters deeper than 300 m and colder than 6°C off Canada. Juveniles occur in shallow water, however, and larvae are almost exclusively neustonic (Kendall and Clark¹). Thus larval development and growth occur in much warmer water than that inhabited by later stages, particularly in the southern portion of the species range.

Sablefish growth has been described by Heyamoto (1962) and Pruter (1954), among others, who used scale annuli to define the growth pattern. More recent work, however, has shown that the age estimates, particularly for older, mature fish, are in error; growth is apparently much slower and longevity much greater than previously thought (Beamish and Chilton 1982). The warmer neustonic habitat of the larvae may result in different growth patterns in early life; ontogenetic changes in growth and habitat are relatively common among deeper living fishes (Boehlert 1982; Luczkovich and Olla 1983). The only observations on growth of young sablefish are those of Heyamoto (1962), who suggested that juveniles of 12-16 cm fork length (FL) were about 6 mo old. In the present study we report on the growth of field-collected larval and juvenile sablefish where age was estimated by enumerating growth increments on the otoliths.

Materials and Methods

Larval and juvenile sablefish were collected in 1981-83. Larvae were taken in 0.5 m neuston nets (Sameoto and Jaroszynski 1969) with 0.505 mm mesh, off the coasts of Oregon and Washington during May 1982 by the RV *Poseydon*. Samples were immediately preserved in 80% ethanol. After sorting,

¹Kendall, A. W., Jr., and J. Clark. 1982. Ichthyoplankton off Washington, Oregon, and northern California, April-May 1980. Processed Rep. 82-11, 44 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. East, Seattle, WA 98102.